Design study of large-scale linear generators for wave energy conversion

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博士学位論文内容要旨
Abstract

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論文題目 Title	Design study of large-scale linear generators for wave energy conversion (波力エネルギー変換のための大型リニア発電機の設計研究)		

Ocean wave energy is an attractive renewable energy source, which exists a great worldwide resource and offers the highest energy density among the renewable energy. Wave energy converters (WECs) have been developed to convert wave energy into electric power. Among them, direct-drive devices are considered more reliable and robust than gearbox or hydraulic systems due to the absence of intermediate mechanical conversion parts.

Permanent magnet linear generators (PM-LGs) are generally adopted to direct-drive wave energy converters (WECs). Nevertheless, these machines are physically large and heavy due to the low moving speed of waves, and they also suffer from the drawbacks of PM demagnetization, uncontrollable airgap flux, and high PM cost. On contrary, high-temperature superconductors (HTSs) exhibits high current-carrying capability, which can generate a higher magnetic field than that achieved by using copper wires or PMs, thus compensating for the low speed of the translator. Therefore, the HTSs have the potential of achieving compact and light machine, which causes little mechanical tension on the heaving buoy if used in WECs. The research in this thesis aims to breakthrough some key design technologies of HTS linear generators used for direct-drive WECs, and explore their advantages in WEC application.

This thesis consists of six chapters, and the contents are organized as follows:

In Chapter I, state of the art of WEC systems and the linear generators (mainly the different types of PM-LGs) used in direct-drive WECs are firstly introduced. Then, the fundamental properties, development and applications of HTSs are described. And two concepts of HTS linear generators proposed for WECs are presented, with the advantages and disadvantages discussed.

In Chapter II, characteristics of ocean waves are firstly investigated to make sure that the studies in this thesis are based on realistic wave data. Then, electrical system of a direct-drive WEC is presented, and the structural merits of the WEC device are highlighted. Next, the buoy movement during one-cycle operation is analyzed, and the relation of buoy size and maximum output power is clarified.

In Chapter III, PM tubular linear generators (PM-TLGs) are designed for the WEC. This chapter focuses on the electrical design method of PM-TLGs and the design results of different PM-TLGs (with PM thickness of 50 mm, 60 mm, and 70 mm, respectively). The electrical design method is described in detail, especially the methods of determining main machine parameters, calculating leakage coefficients with 3-D simulation, and evaluating PM operating point. Optimum design results of the PM-TLGs are presented and discussed to select a most desirable one. And the magnetic flux density distribution of the PM-TLG with 60 mm PMs is analyzed to verify the correctness of the design method.

Chapter IV aims to present the key design technologies of HTS-TLGs, clarify the induced voltage characteristics of the HTS-TLGs, introduce the cooling system and describe the evaluation of cooling power. The contents are organized as follows. Firstly, conceptual structure of the HTS-TLG is described in detail. Then, the key electrical design technologies of HTS-TLGs are presented, including the electrical design process, the determination of main machine parameters, the calculation of magnetomotive force (MMF), and the approaches of obtaining leakage coefficients and HTS heat loss with 3-D simulation. By using this electrical design method,

a 1 MW HTS-TLG is designed for the WEC, and the design results are shown. Then, waveforms of electrical frequency, induced phase voltage, and rectified 3-phase voltage of the HTS-TLG are plotted to show its induced voltage characteristics. Besides, an economic way of connecting output power to grid is proposed, which benefits for reducing expensive filters. Moreover, cooling system of the WEC device is introduced, with the cryogenic vessels presented, various heat loss calculated, and cooling power evaluated.

In Chapter V, different TLGs designed for the WEC are compared and discussed. Firstly, three types of TLGs are described, which are HTS-TLG, PM-TLG, and Cu-TLG (with field exciting component made of copper wires). These TLGs are compared from the aspects of machine performance including the physical and electromechanical characteristics, and the costs. Furthermore, a 2 MW HTS-TLG is designed based on a different set of wave data, which is compared to another HTS-LG designed with approximate wave data to show the advantages of the proposed structure, and is further compared to the 1 MW HTS-TLG to show the influence of wave data on the generator design.

Chapter VI summarizes the research conducted and results presented in this study. The contributions in this thesis are highlighted. Moreover, the possible improvements are proposed for the future research.